SURGES IN THE INTERMEDIATE POOL OF LONG SAULT CANAL ST. LAWRENCE RIVER

Hydraulic Model Investigation

TECHNICAL REPORT NO. 2-489

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PREFACE

The hydraulic model investigation of surges in the intermediate pool of Long Sault Canal, St. Lawrence River, was authorized by the Office, Chief of Engineers, in the fifth indorsement to the North Central Division letter dated 2 August 1955, subject: "St. Lawrence Seaway, Fuse Plug Dike." The study was conducted for the Buffalo District by the Hydraulics Division of the Waterways Experiment Station during September and October 1956. Results of the model tests were furnished to the Buffalo District in the form of interim reports as the various tests were completed; this report supersedes and incorporates the results presented in all interim reports.

During the course of the model study, Mr. J. P. Davis of the Buffalo District and Mr. W. Grothaus of the St. Lawrence Seaway Development Corporation served in liaison and advisory capacities. The study was carried out under the supervision of the following engineers of the Waterways Experiment Station: Mr. E. P. Fortson, Jr., Chief of the Hydraulics Division; Mr. G. B. Fenwick, Chief of the Rivers and Harbors Branch; and Mr. E. B. Lipscomb, Chief of the Potamology Section. The study was conducted by Mr. A. M. Gill, assisted by Messrs. G. F. Myers, J. W. Carsley, and A. E. Hullum. This report was prepared by Mr. Lipscomb, under the supervision of Messrs. Fenwick and Fortson.

CONTENTS

SUMMARY

Tests to investigate surges that could occur in the intermediate pool of Long Sault Canal between Eisenhower and Grass River Locks through accidental failure of the gates in the upstream lock were conducted on a fixed-bed model built to a horizontal scale of 1 to 200 and a vertical scale of 1 to 100.

The test results showed that the maximum height of the surge above normal pool elevation would be 4.5 ft at the downstream (Grass River) lock when closing of the emergency lift gate of Eisenhower Lock was started 10 minutes after the miter gates failed and closure was completed in 19 additional minutes. For these conditions, the design height of the Grass River Lock walls is adequate to contain the surges produced. However, if water were prevented from flowing onto overbank areas adjacent to the canal, surges at Grass River Lock would increase to 14.4 ft above normal pool elevation.

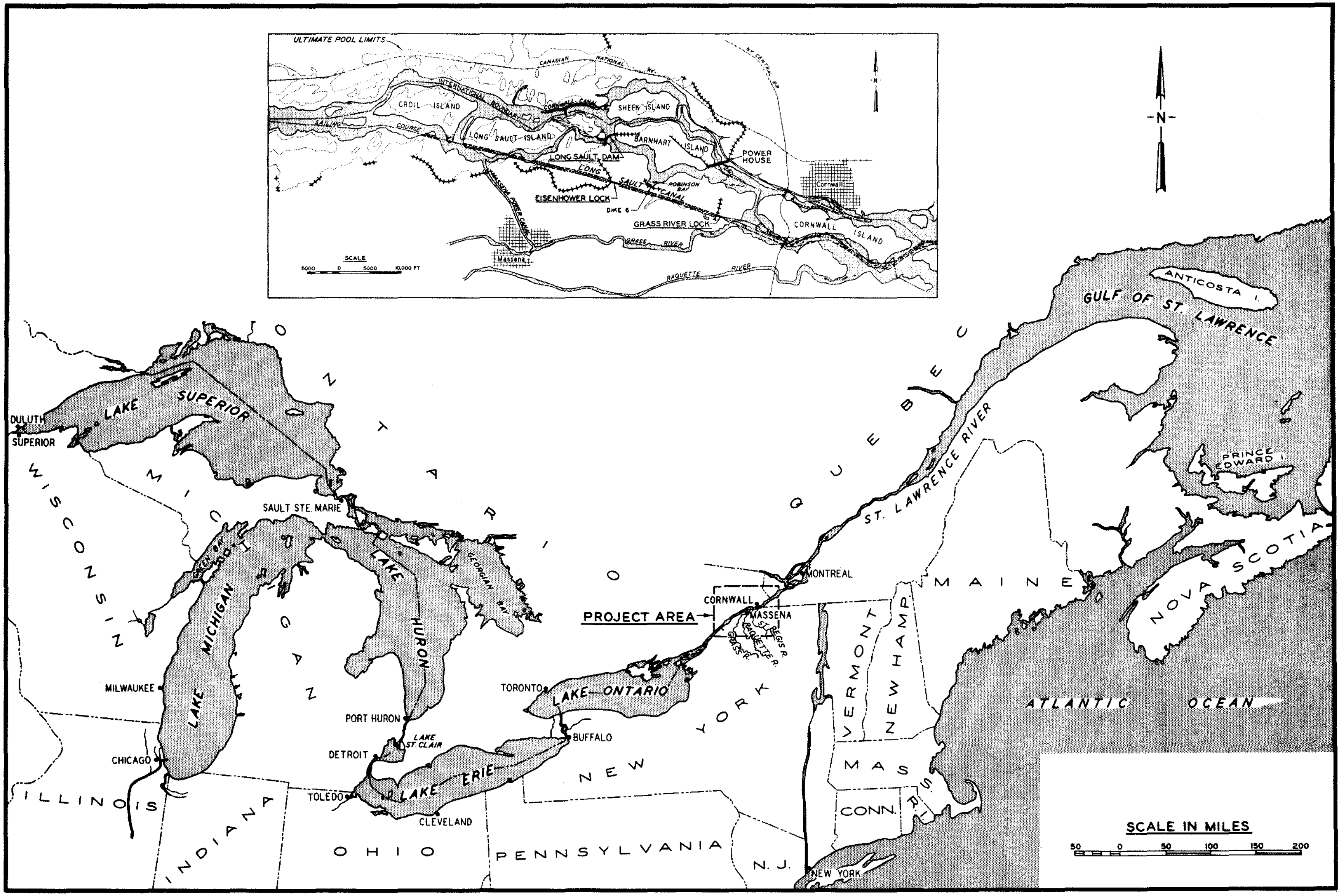

Fig. 1. Vicinity map

SURGES IN THE INTERMEDIATE POOL OF LONG SAULT CANAL, ST. LAWRENCE RIVER

Hydraulic Model Investigation

PART I: INTRODUCTION

Location and Description of Prototype

1. The Long Sault Canal, one of the major features of the St. Lawrence Seaway project, is located in the International Boundary Section of the St. Lawrence River approximately 74 miles upstream of Montreal, Quebec, and about 2 miles north of Massena, New York (see fig. 1). The canal with its entrance channels, retaining dikes, and locks comprises the deep-draft navigation channel necessary to bypass the Long Sault Dam and the Barnhart powerhouse. The 90-ft difference in water-surface elevations created by the dam and powerhouse is overcome by two locks located in the canal. Because of the topographic features of the area, the upper lock, Eisenhower, is located near Robinson Bay and the lower lock, Grass River, near the mouth of Grass River.

2. The canal is approximately 10 miles long with a bottom width of generally 442 ft. The length of the intermediate pool between the two locks is 18,000 ft. Bottom grade of the canal through the intermediate pool is 170.5 ft msl and the bottom width is 442.0 ft. Side slopes vary from 1 on 2 to 1 on 12, depending on the type of soil forming the adjacent overbank. Practically all of the canal passes through pool areas with open water on both sides of the navigation channel. Material excavated in construction of the canal is spoiled on the overbank along the canal in specified disposal areas.

3. The Eisenhower and Grass River Locks are generally similar in design. Lock dimensions and pertinent data are:

Width	80 ft	Service gate type	Miter
Length between upper and lower service gates	860 ft	Emergency gate (upper lock) type	Vertical lift
Length, upper gate pintle to fender	768 ft	Upper pool elevation	242 ft msl
Minimum depth over sills	30 ft	Intermediate pool elevation	200 ft msl
Maximum lift	51.5 ft	Lower pool elevation	158 ft msl
Normal lift	38-42 ft		

The Problem

4. During the design of the Long Sault Canal, consideration was given to the possible occurrence of destructive or undesirable surges in the intermediate pool between the two locks. It was recognized that should an accident lead to failure of the miter gates of Eisenhower Lock, water would flow directly through the lock and into the intermediate pool and produce a surge wave in the canal before the emergency lift gate at Eisenhower Lock could be closed. The height and force of this surge wave could be of sufficient magnitude to damage the Grass River Lock system. To provide information as to what could take place in the pool between the two locks under these conditions, the maximum discharge and surge wave height were computed.

5. In arriving at the maximum discharge that would pass through the lock before the emergency lift gate could be put in operation, the following assumptions were made:

a. The vessel entering or in the lock that caused the failure of the miter gate would be swept out of the lock.

b. The position of the miter gate would be such as to provide free flow through the lock.

c. The upper and intermediate pool elevations would be 242.0 and 200.0 ft msl, respectively.

6. Based on these assumptions, the discharge through the lock into the intermediate pool was computed to be approximately 53,000 cfs. A maximum positive surge in the intermediate pool resulting from such a discharge through Eisenhower Lock was computed to be approximately 3.5 ft, which upon being reflected at Grass River Lock would double in magnitude. The resulting positive surge of about 7 ft at Grass River Lock would be further increased by about 1 ft as a result of the increase in pool elevation during the 9 to 10 minutes in which the surge traveled the length of the intermediate pool. An 8-ft momentary increase in the intermediate pool level at Grass River Lock would result in an elevation of 208.0 or about 3 ft higher than the top of the lock wall. If the lock gates and walls were high enough to completely stop the wave, the surge would more than double its height upon striking the lock gate, and a 17.2-ft surge would result. With the present gate and wall elevation of 205.0, the wave would wash over

the approach walls and lock gate, and a surge height somewhat less than 17.2 ft, perhaps around 10 or 12 ft, would result. The static water load on the gates and walls would be increased accordingly.

7. The 17.2-ft height was obtained by applying Green's Law (formula 51, p. 737, of Engineering Hydraulics by Hunter Rouse) which states that the wave height, h, in a transition varies inversely as the square root of the channel surface width, b, and inversely as the fourth root of the channel depth, d, thus $h \sim b^{-1/2} d^{-1/4}$. The computed surge heights discussed in the preceding paragraph are based on the assumption that the surge height would not be reduced by friction in the 18,000-ft canal or by dissipation of the surge energy as the waves pass through the irregular broad pool areas on the overbank adjacent to the navigation channel. Application of these two factors would tend to reduce the surge height.

Purpose of Model Study

8. The general purposes of the model study were to check the validity of the surge computations discussed in paragraphs 4-7, and to investigate possible means of reducing the magnitude of any surge waves that would overtop the Grass River Lock walls. The specific purpose of the model study was to determine the magnitude of the surge at the upper Grass River Lock gate for various combinations of the following conditions: (a) failure of the Eisenhower Lock lower miter gate; (b) failure of Eisenhower Lock upper miter gate; (c) drawdown of upper pool by flow through Eisenhower Lock; (d) no drawdown of upper pool, i.e., pool maintained at el 242.0; (e) revisions in Grass River Lock upper guard wall alignment; (f) release of flow from the intermediate pool over a 1200-ft lowered section (cut to el 202.5) of dike 6 (see fig. 1 and plate 1); (g) emergency lift gate not closed; and (h) raising the elevation of all overbank areas adjacent to the canal so that no overbank flow could occur and all water would remain in the canal.

PART II: THE MODEL

Description

9. The model was constructed to linear scale ratios, model to prototype, of 1:200 horizontally and 1:100 vertically, with a resultant geometric distortion of 2. It reproduced approximately 4.1 miles of the Long Sault Canal between canal stations 340+00 and 557+00 (plate 1). This section of the canal includes part of the upper pool, Eisenhower Lock, the intermediate pool, dike 6, and Grass River Lock.

10. The model was of the fixed-bed type with all channel and overbank areas molded in cement mortar to conform to the prototype (fig. 2). Dimensions of the canal used in the model construction are shown in plate 1. Eisenhower and Grass River Locks were fabricated of wood in accordance with the details shown in plate 2. General dimensions of the two locks were identical, with the top of the Eisenhower Lock wall set at el 251.5 and the top of the Grass River Lock wall set at el 205.0.

Scale Relationships

11. The accepted equations of hydraulic similitude, based upon the Froudian relationships, were used to express the mathematical relationships between the dimensions and hydraulic quantities of the model and the prototype. The general relationships are presented in the following tabulation:

Dimension	Scale Relationship
Horizontal	$L_r = 1:200$
Vertical	$D_r = 1:100$
Area, horizontal	$A_r = L_r^2 = 1:40,000$
Area, vertical	$A_r = L_r D_r = 1:20,000$
Velocity	$V_r = D_r^{1/2} = 1:10$
Time	$T_r = L_r D_r^{-1/2} = 1:20$
Discharge	$Q_r = L_r D_r^{3/2} = 1:200,000$

12. Measurements in the model of discharge, water-surface elevation

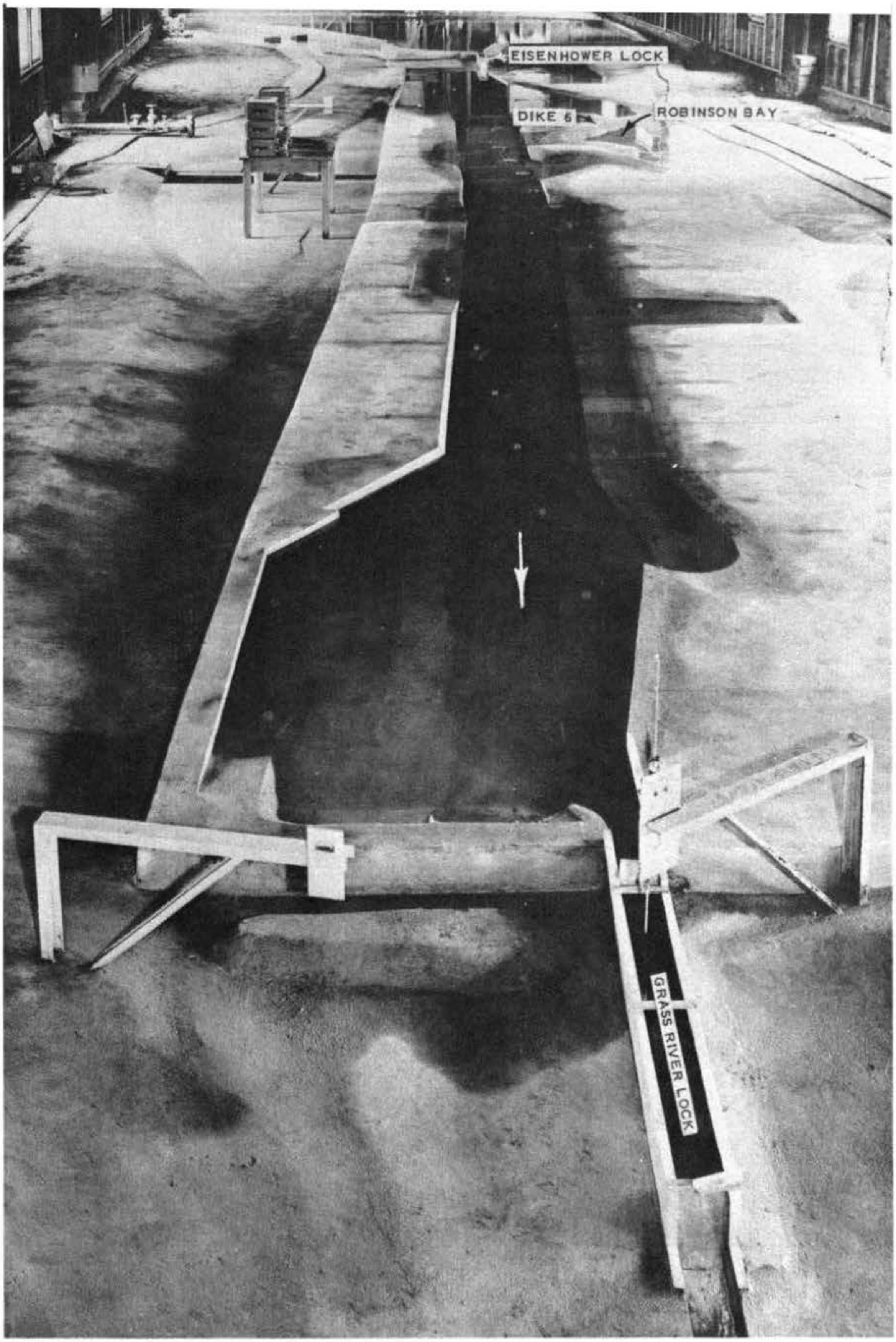

Fig. 2. Upstream view of the model

and time are transferable quantitatively from model to prototype by means of the preceding scale relationships.

Appurtenances

13. The model was located near an artificial lake from which water was pumped to supply the model. The upper pool was regulated by a gate valve and an overflow pipe. The intermediate pool was regulated by operating the Eisenhower and Grass River Lock gates. Water was allowed to flow from the upper pool through Eisenhower Lock into the intermediate pool until the proper water-surface elevation was obtained. Point gages were used to measure water-surface elevations in the upper and intermediate pools.

14. Wave heights were automatically recorded with gages spaced throughout the intermediate pool, consisting of resistance staffs installed in a direct-current circuit (fig. 3). External contacts were exposed along the face of the gage staff in vertical increments of 0.002 ft. Therefore, the gages were capable of measuring vertical movement of the water surface with an accuracy of 0.002 ft model (0.2 ft prototype). The resistors of the electrical circuit were so designed that the current through the circuit varied directly with the submergence of the gage staff in water. Electrical leads from the gage staff were connected to a resistance-type bridge circuit and then to a carrier-type amplifier. The output voltage from the amplifier passed to a pen motor recorder which recorded the changes in voltage on a chart driven at a constant speed.

15. Stop watches were used to time the gate operations at Eisenhower Lock and to determine the time of overtopping of Grass River Lock.

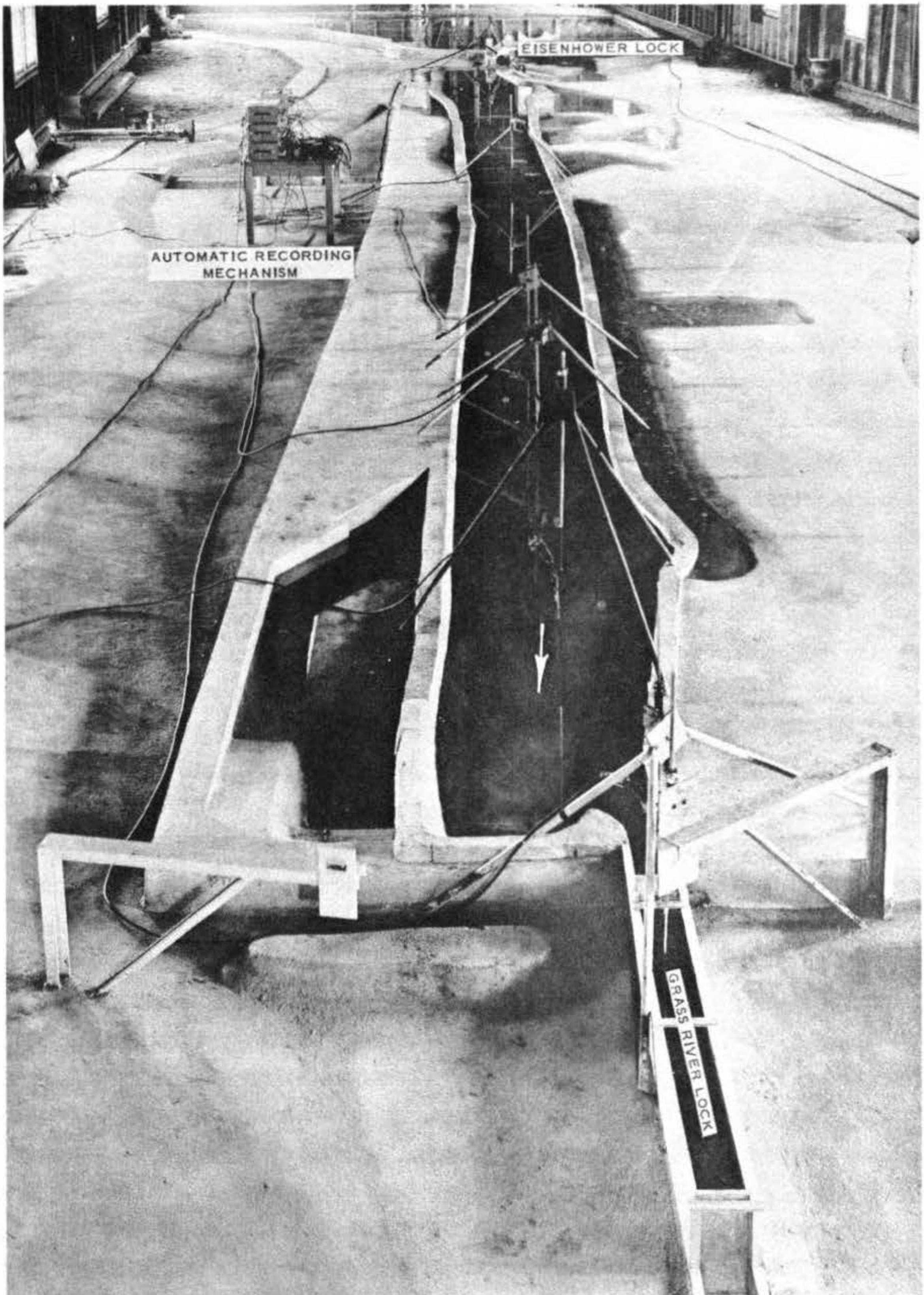

Fig. 3. The model with overbank areas eliminated and the gages located for test 11

PART III: NARRATIVE OF TESTS

Test Procedure

16. One general operating procedure was used in all the tests to investigate surges in the intermediate pool between Eisenhower and Grass River Locks. This procedure followed as closely as possible the basic assumptions made in computing the surge height as discussed in paragraphs 4 to 7. Prior to each test the upper pool was filled to el 242.0 and the intermediate pool was filled to el 200.0. After the pools had become stable, either the upper or the lower miter gate of Eisenhower Lock was suddenly opened, and flow from the upper pool through the lock to the lower pool was allowed to continue for 10 minutes* at which time closure of the emergency lift gate was begun. Nineteen minutes* were allowed for complete closure of the emergency gate. Continuous observations of the height of the surge in the intermediate pool were recorded by five of the gages described in paragraph 14 spaced at about equal distances along the canal (fig. 3).

Test 1

17. For test 1 the model configurations were as originally constructed (see plates 1 and 2). The operating procedure described in paragraph 16 was used with the lower miter gate failing. The upper pool was permitted to be drawn down by the flow through Eisenhower Lock.

18. The upper pool was drawn down about 1.5 ft during the 29-min period between gate failure and final closure of the emergency lift gate. The major portion (1.1 ft) of the drawdown occurred during the 10-min period of free flow. Rate of flow during this 10-min period averaged 55,000 cfs. Plate 3 shows the surge patterns observed at the five continuous recording gages located in the intermediate pool for a period of 1 hr, 40 min. These patterns show that an interval of 10 min was required for the initial surge to travel the 18,000 ft between the two locks. The

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* These times were assumed reasonable by North Central Division office.

maximum surge observed at the Grass River Lock was 4.5 ft and occurred about 22 min after gate failure. Although the test was stopped before the pool became stable, it appears from examination of the surge patterns that the intermediate pool was raised about 3 ft by flow through Eisenhower Lock.

Test 2

19. Test conditions and operating procedure for test 2 were the same as for test 1 except that the upper, instead of the lower, miter gate of Eisenhower Lock was failed.

20. The results of test 2 are shown in plate 4. Comparison of the results of tests 1 and 2 indicates that failure of the upper miter gate would produce about the same surge characteristics and heights as observed when the lower gate failed.

Tests 3 and 4

21. In tests 1 and 2 the upper pool was drawn down about 1.5 ft by the flow through Eisenhower Lock. As the upper pool is a part of the large power pool above the Barnhart Island powerhouse, it was felt that under actual prototype conditions the flow through Eisenhower Lock would not affect upper pool levels significantly. Tests 3 and 4 were identical with tests 1 and 2, respectively, except that in tests 3 and 4 the upper pool was maintained at el 242.0 throughout the test.

22. The results of tests 3 and 4 are shown in plates 5 and 6. Maintenance of the upper pool at el 242.0 did not change the time of travel of the surge or increase the surge height at Grass River Lock over those obtained when the upper pool was permitted to draw down. However, the total volume of water passing through Eisenhower Lock was increased as evidenced by the increase in intermediate pool levels from 3.0 ft in tests 1 and 2 to about 3.5 ft in tests 3 and 4.

Test 5

23. The purpose of test 5 was to determine if a change in alignment

of the upper guard wall at Grass River Lock would influence the surge pattern at the lock. Model operating procedures and conditions for test 5 were the same as for test 3 except that the curved upper guard wall in test 3 was replaced by a right-angle wall for test 5 (see plate 2).

24. Visual observations and point gage measurements indicated that changing the alignment of the upper guard wall of Grass River Lock would have very little, if any, effect on the surge pattern; therefore, a continuous record of the surge was not made.

Tests 6 and 7

25. Tests 6 and 7 differed from tests 3 and 4, respectively, only in that the emergency lift gate at Eisenhower Lock was not closed after the miter gate failed. The purpose of these tests was to determine the time interval between gate failure and overtopping of the Grass River Lock walls (el 205.0).

26. The results of tests 6 and 7, presented in plate 7, show that if the emergency lift gate were not closed the lock walls at Grass River Lock would be overtopped about 37 min after failure of either of the Eisenhower Lock miter gates.

Tests 8 and 9

27. Tests 8 and 9 differed from tests 6 and 7, respectively, in that a 1200-ft section of dike 6 (see plate 1) separating the intermediate pool from Robinson Bay was lowered to el 202.5 ft msl, or 5.5 ft lower than the design elevation of 208.0 ft msl used in previous tests. The purpose of reducing the height of dike 6 was to provide an escape channel for water in the intermediate pool. It was felt that the escape of water through this channel would reduce the surge at Grass River Lock and possibly prevent overtopping of the lock walls.

28. Visual observations of the tests revealed that with the escape channel in operation the walls of the Grass River Lock would be overtopped about 40 min after gate failure at the Eisenhower Lock. Thus, the elapsed time between gate failure and lock wall overtopping was increased only about 3 min by permitting flow over dike 6.

Tests 10 and 11

29. The purpose of tests 10 and 11 was to check the computed surge height discussed in paragraphs 4-7. Model configurations in all previous tests had been in accordance with the proposed design specifications, or slight modifications thereto, which were considerably different from the conditions assumed in the computations. The major difference was that in the computation of the surge it was assumed that all water would remain in the navigation channel with no reduction in surge height due to overbank flow as occurred in the model tests. Therefore, for tests 10 and 11, the overbank areas in the intermediate pool were eliminated by extending the canal side slopes up to el 215.0 (fig. 3). In order to contain the anticipated high surge in the canal, the walls and gate at Grass River Lock were also raised to el 215.0. Model operating procedures for tests 10 and 11 were the same as for tests 3 and 4, respectively.

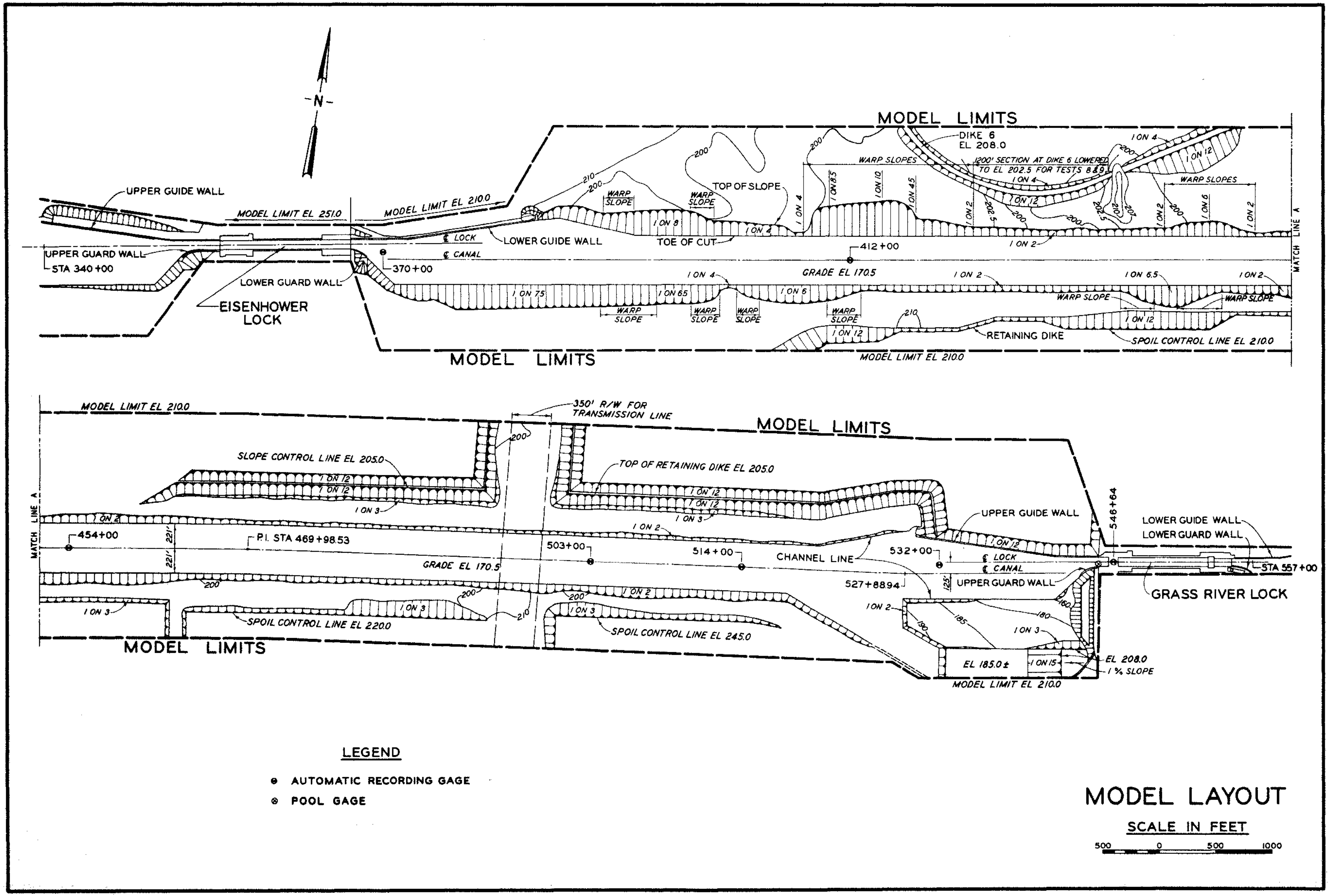
30. The results of tests 10 and 11 are presented in plates 8, 9, and 10. Plate 9 shows the results of a rerun of test 10 with the two upstream recording gages relocated at stations 514+00 and 532+00 (see plate 1) so that the surge action in the vicinity of the Grass River Lock entrance could be better defined.

31. Elimination of flow into the overbank areas increased the wave celerity and reduced from 10 min to 9 min the time required for the wave to travel the length of the intermediate pool. The maximum height of surge at Grass River Lock was 14.4 ft, which agrees fairly closely with the computed 17.2 ft. Comparison of the results of tests 10 and 11 shows that failure of the lower versus the upper miter gate did not affect the surge height at Grass River Lock.

PART IV: CONCLUSIONS

32. Model tests of surges in the intermediate pool of Long Sault Canal provided the basis for the following conclusions:

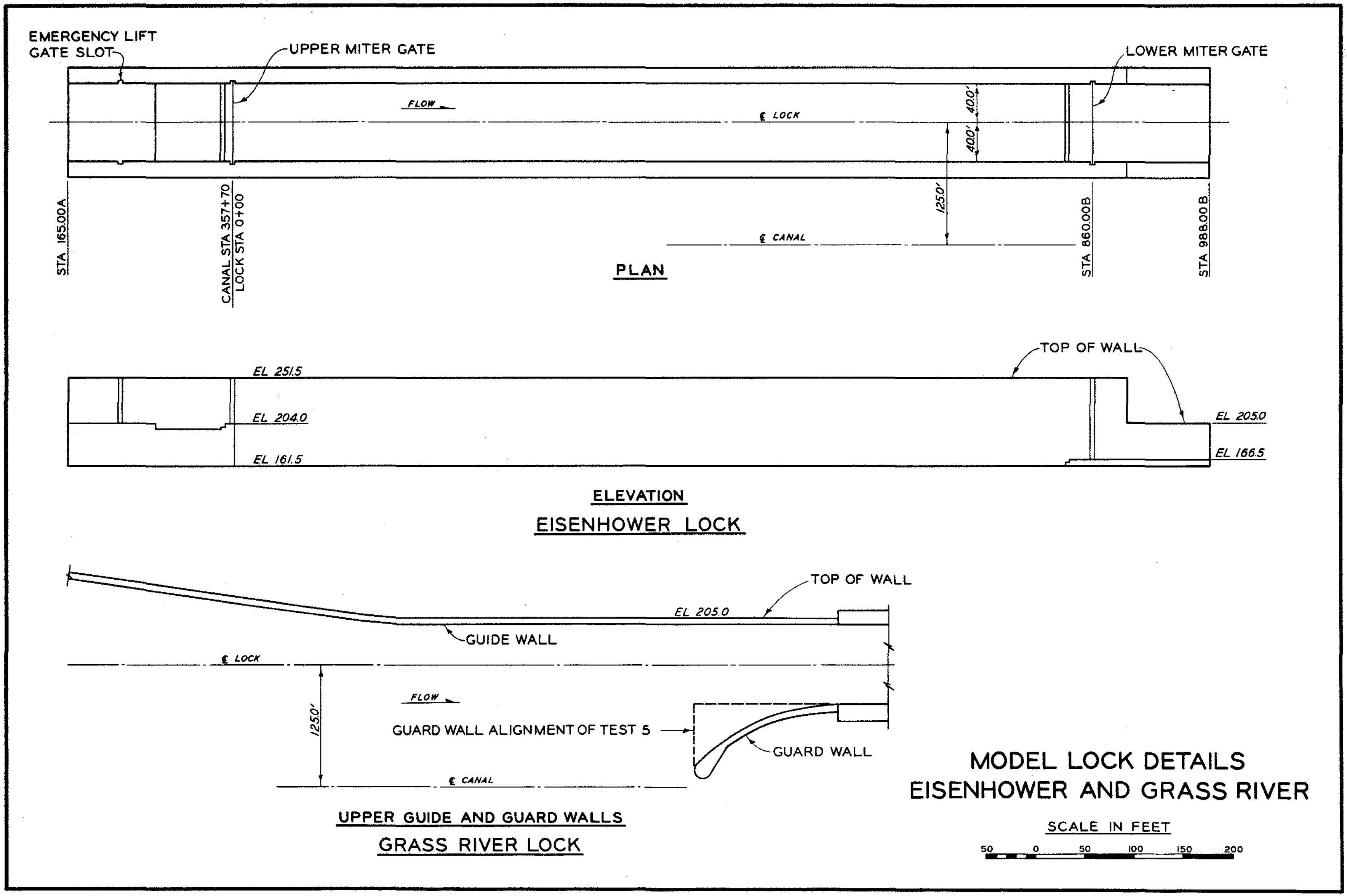
- a. For the conditions proposed in the design specifications, the height of the Grass River Lock walls is adequate to contain any surge produced by failure of either of the Eisenhower Lock miter gates, provided the emergency lift gate is placed in operation within 10 min after the gate fails and closure is completed in 19 additional min.
- b. The overflow section in dike 6 would not be an effective means of releasing flow from the intermediate pool in event the lift gate could not be closed.
- c. If all overbank flow were eliminated in the intermediate pool, the surge resulting from failure of the Eisenhower Lock miter gate would inundate the Grass River Lock area.



N
MODEL LIMITS
UPPER GUIDE WALL
MODEL LIMIT EL 251.0
MODEL LIMIT EL 210.0
UPPER GUARD WALL
STA 340+00
EISENHOWER LOCK
LOWER GUARD WALL
LOWER GUIDE WALL
℄ LOCK
℄ CANAL
370+00
TOE OF CUT
TOP OF SLOPE
WARP SLOPE
WARP SLOPES
DIKE 6
EL 208.0
1200' SECTION AT DIKE 6 LOWERED TO EL 202.5 FOR TESTS 8 & 9
412+00
GRADE EL 170.5
RETAINING DIKE
SPOIL CONTROL LINE EL 210.0
MATCH LINE A
350' R/W FOR TRANSMISSION LINE
SLOPE CONTROL LINE EL 205.0
TOP OF RETAINING DIKE EL 205.0
454+00
P.I. STA 469+98.53
503+00
514+00
532+00
527+88.94
CHANNEL LINE
UPPER GUIDE WALL
UPPER GUARD WALL
546+64
LOWER GUIDE WALL
LOWER GUARD WALL
STA 557+00
GRASS RIVER LOCK
SPOIL CONTROL LINE EL 220.0
SPOIL CONTROL LINE EL 245.0
EL 185.0±
EL 208.0
1 ¾ SLOPE
LEGEND
AUTOMATIC RECORDING GAGE
POOL GAGE
MODEL LAYOUT
SCALE IN FEET
500 0 500 1000

PLATE 1

PLATE 2


EMERGENCY LIFT GATE SLOT
UPPER MITER GATE
LOWER MITER GATE
FLOW
℄ LOCK
40.0'
40.0'
125.0'
℄ CANAL
STA 165.00A
CANAL STA 357+70
LOCK STA 0+00
STA 860.00B
STA 988.00 B
PLAN
TOP OF WALL
EL 251.5
EL 204.0
EL 161.5
EL 205.0
EL 166.5
ELEVATION
EISENHOWER LOCK
TOP OF WALL
EL 205.0
GUIDE WALL
℄ LOCK
FLOW
125.0'
GUARD WALL ALIGNMENT OF TEST 5
GUARD WALL
℄ CANAL
UPPER GUIDE AND GUARD WALLS
GRASS RIVER LOCK
MODEL LOCK DETAILS
EISENHOWER AND GRASS RIVER
SCALE IN FEET
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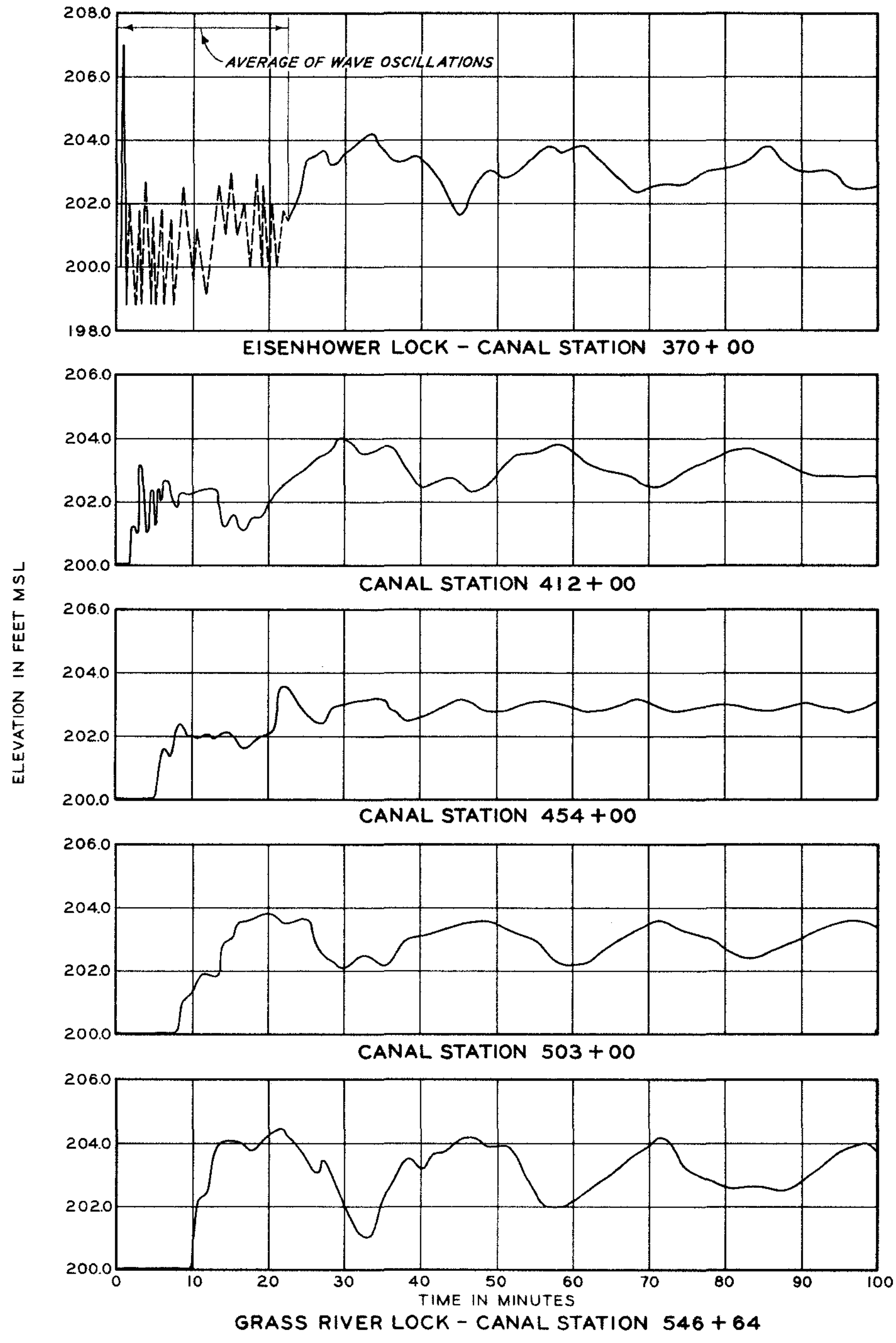
0
50
100
150
200

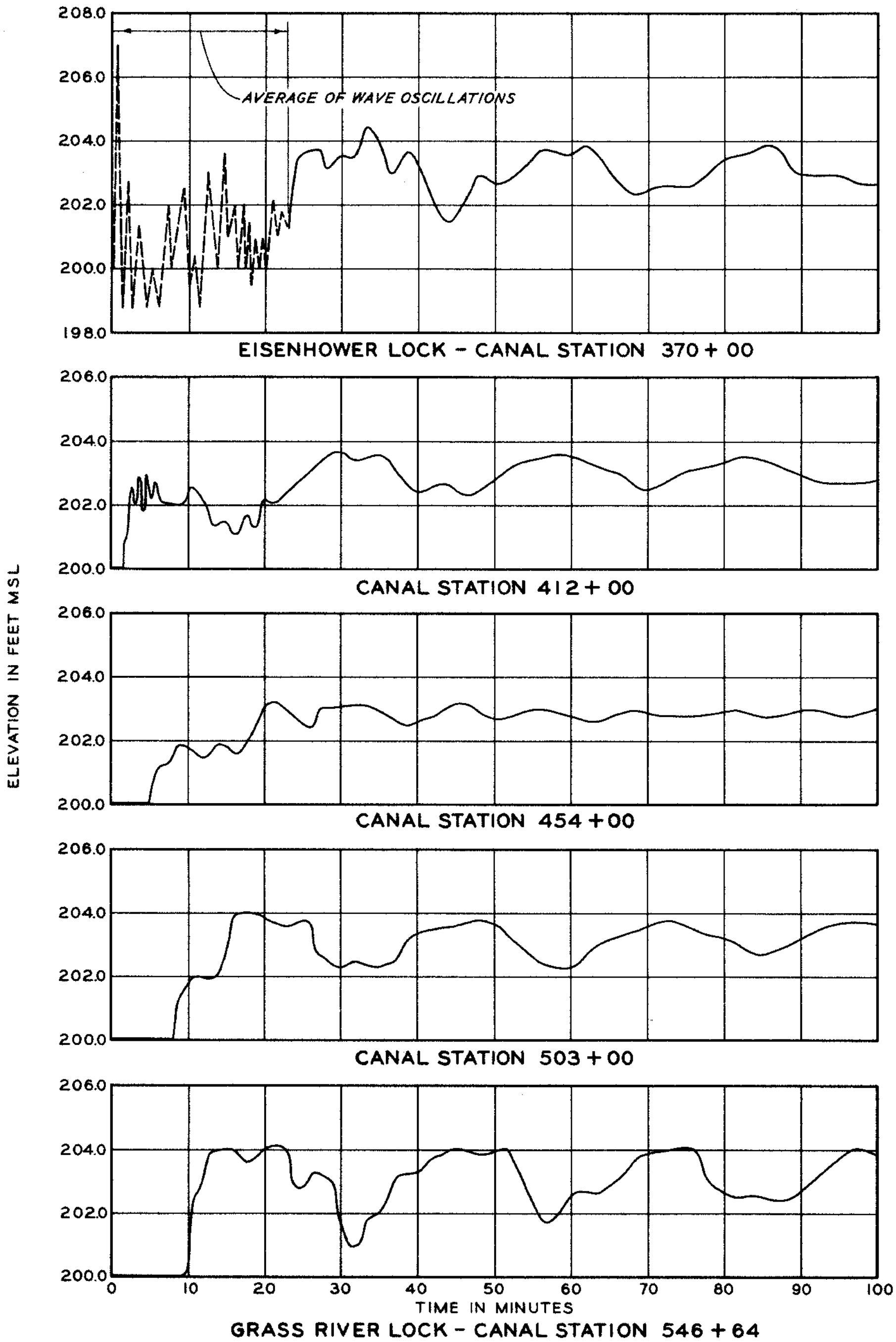


TEST CONDITIONS

1.	FAILED LOWER MITER GATE AT EISENHOWER LOCK	
2.	FREE FLOW OF WATER THROUGH LOCK	10.0 MIN
3.	CLOSING TIME OF LIFT GATE	19.0 MIN
4.	TOTAL TIME FROM GATE FAILURE TO GATE CLOSURE	29.0 MIN
5.	UPPER POOL ELEVATION PRIOR TO GATE FAILURE	242.0 FT
6.	INTERMEDIATE POOL ELEVATION PRIOR TO GATE FAILURE	200.0 FT
7.	UPPER POOL ELEVATION AFTER LIFT GATE CLOSED	240.5 FT

SURGES IN INTERMEDIATE POOL

SURGE TEST 1

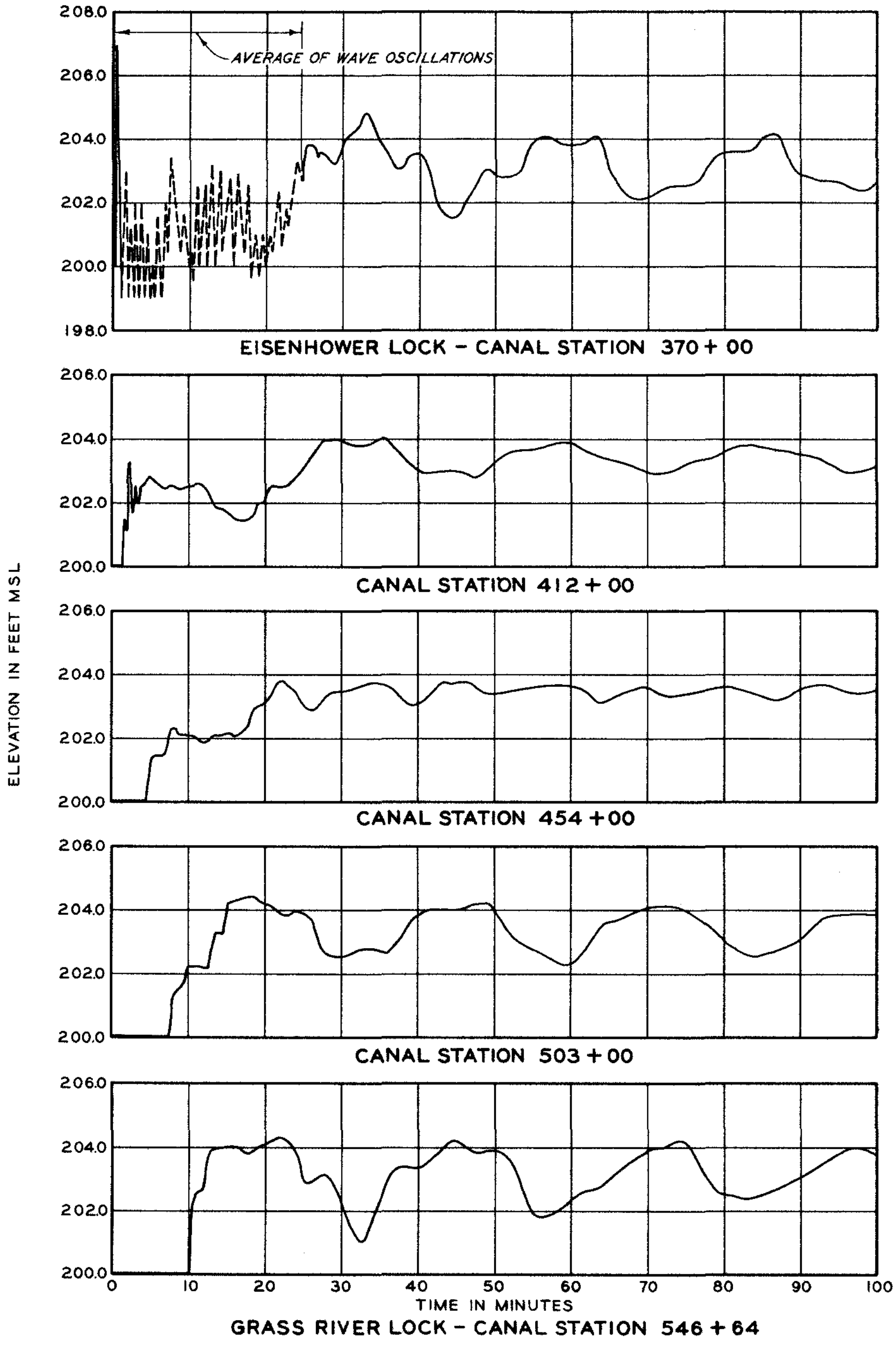


TEST CONDITIONS

1.	FAILED UPPER MITER GATE AT EISENHOWER LOCK	
2.	FREE FLOW OF WATER THROUGH LOCK	10.0 MIN
3.	CLOSING TIME OF LIFT GATE	19.0 MIN
4.	TOTAL TIME FROM GATE FAILURE TO GATE CLOSURE	29.0 MIN
5.	UPPER POOL ELEVATION PRIOR TO GATE FAILURE	242.0 FT
6.	INTERMEDIATE POOL ELEVATION PRIOR TO GATE FAILURE	200.0 FT
7.	UPPER POOL ELEVATION AFTER LIFT GATE CLOSED	240.5 FT

SURGES IN INTERMEDIATE POOL

SURGE TEST 2

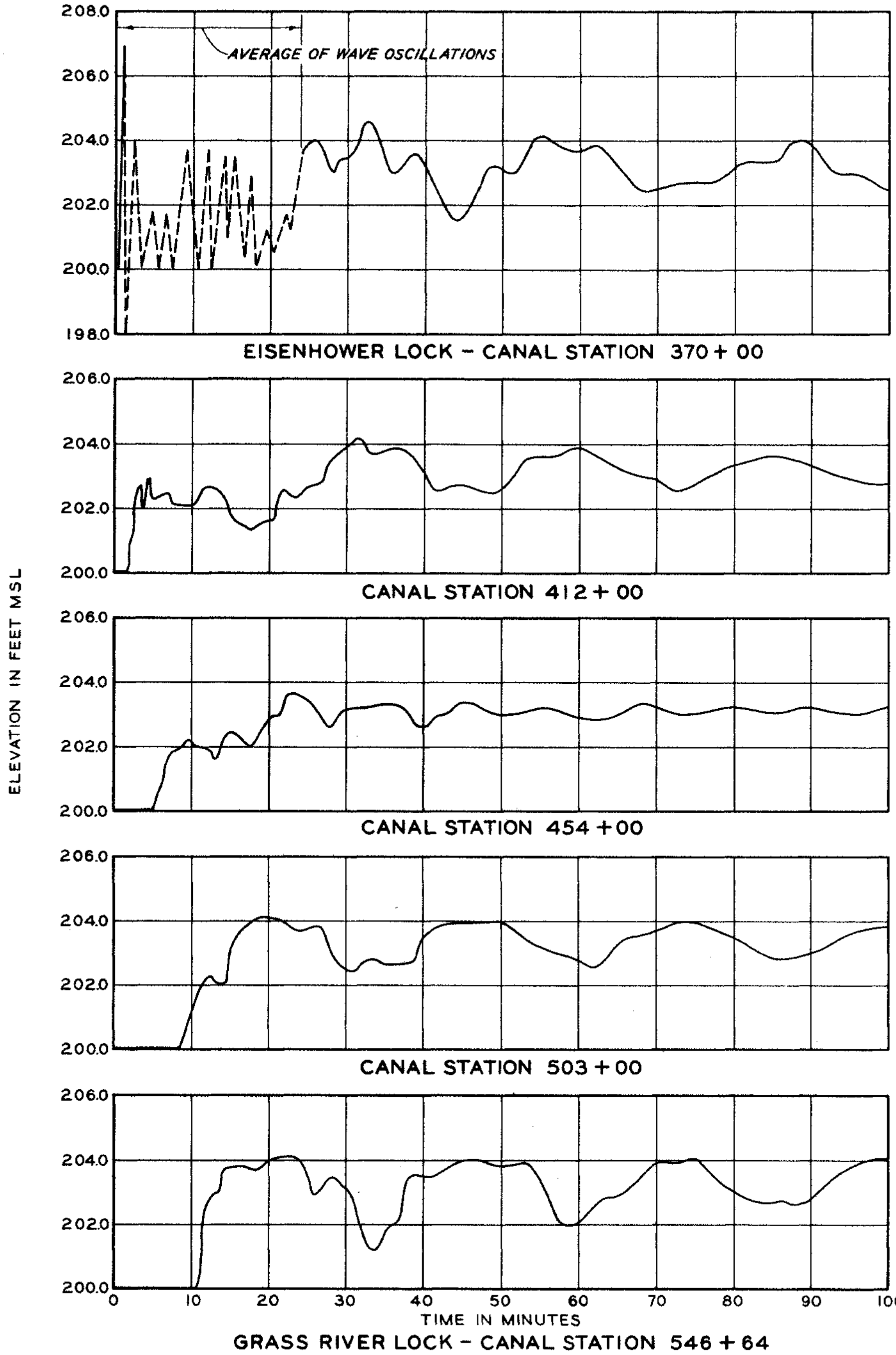


TEST CONDITIONS

1.	FAILED LOWER MITER GATE AT EISENHOWER LOCK	
2.	FREE FLOW OF WATER THROUGH LOCK	10.0 MIN
3.	CLOSING TIME OF LIFT GATE	19.0 MIN
4.	TOTAL TIME FROM GATE FAILURE TO GATE CLOSURE	29.0 MIN
5.	UPPER POOL ELEVATION PRIOR TO GATE FAILURE	242.0 FT
6.	INTERMEDIATE POOL ELEVATION PRIOR TO GATE FAILURE	200.0 FT
7.	UPPER POOL ELEVATION AFTER LIFT GATE CLOSED	242.8 FT

SURGES IN INTERMEDIATE POOL

SURGE TEST 3

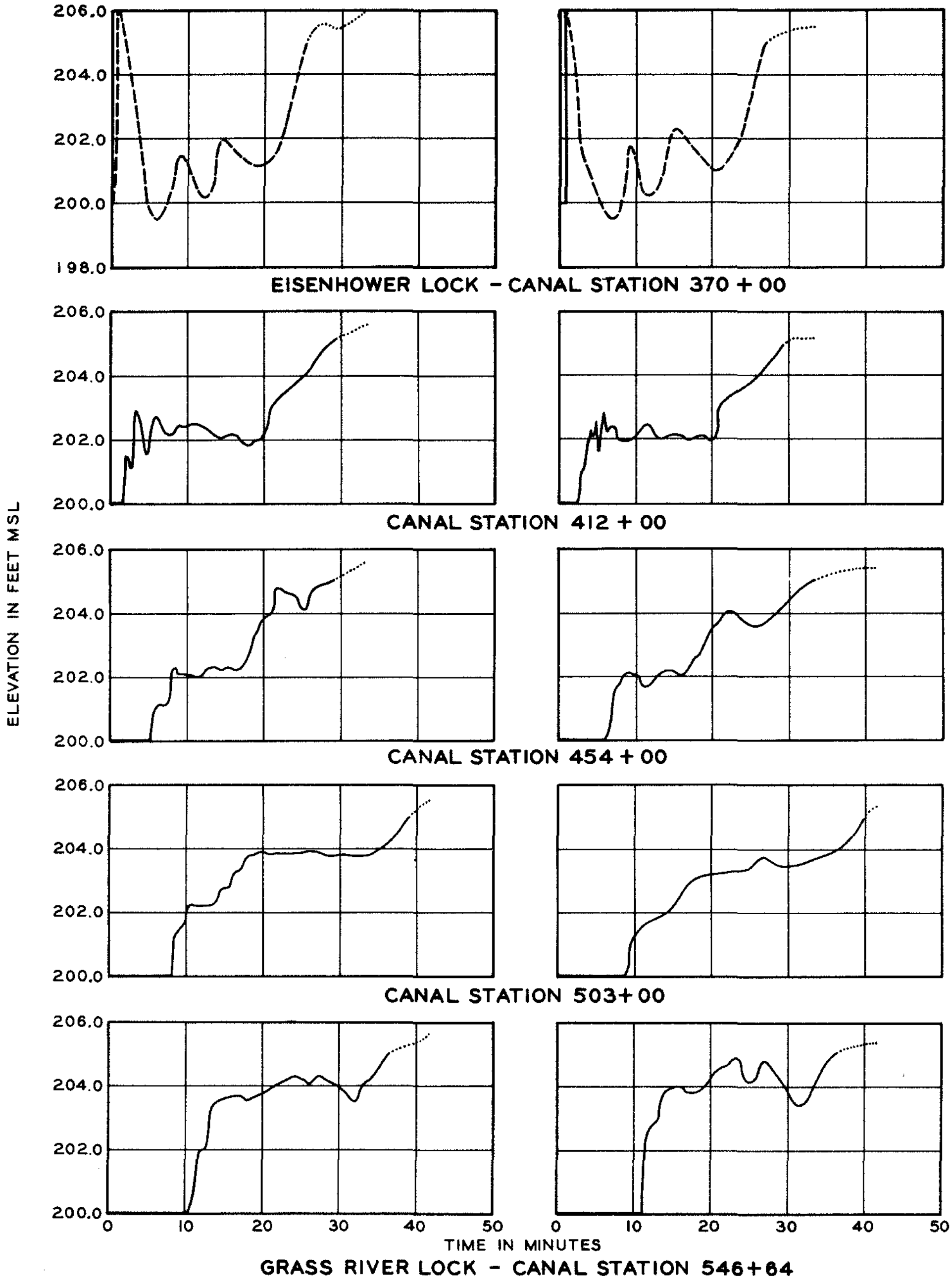


TEST CONDITIONS

1.	FAILED UPPER MITER GATE AT EISENHOWER LOCK	
2.	FREE FLOW OF WATER THROUGH LOCK	10.0 MIN
3.	CLOSING TIME OF LIFT GATE	19.0 MIN
4.	TOTAL TIME FROM GATE FAILURE TO GATE CLOSURE	29.0 MIN
5.	UPPER POOL ELEVATION PRIOR TO GATE FAILURE	242.0 FT
6.	INTERMEDIATE POOL ELEVATION PRIOR TO GATE FAILURE	200.0 FT
7.	UPPER POOL ELEVATION AFTER LIFT GATE CLOSED	242.0 FT

SURGES IN INTERMEDIATE POOL

SURGE TEST 4



TEST 6
(FAILED LOWER MITER GATE AT EISENHOWER LOCK)

TEST 7
(FAILED UPPER MITER GATE AT EISENHOWER LOCK)

LEGEND

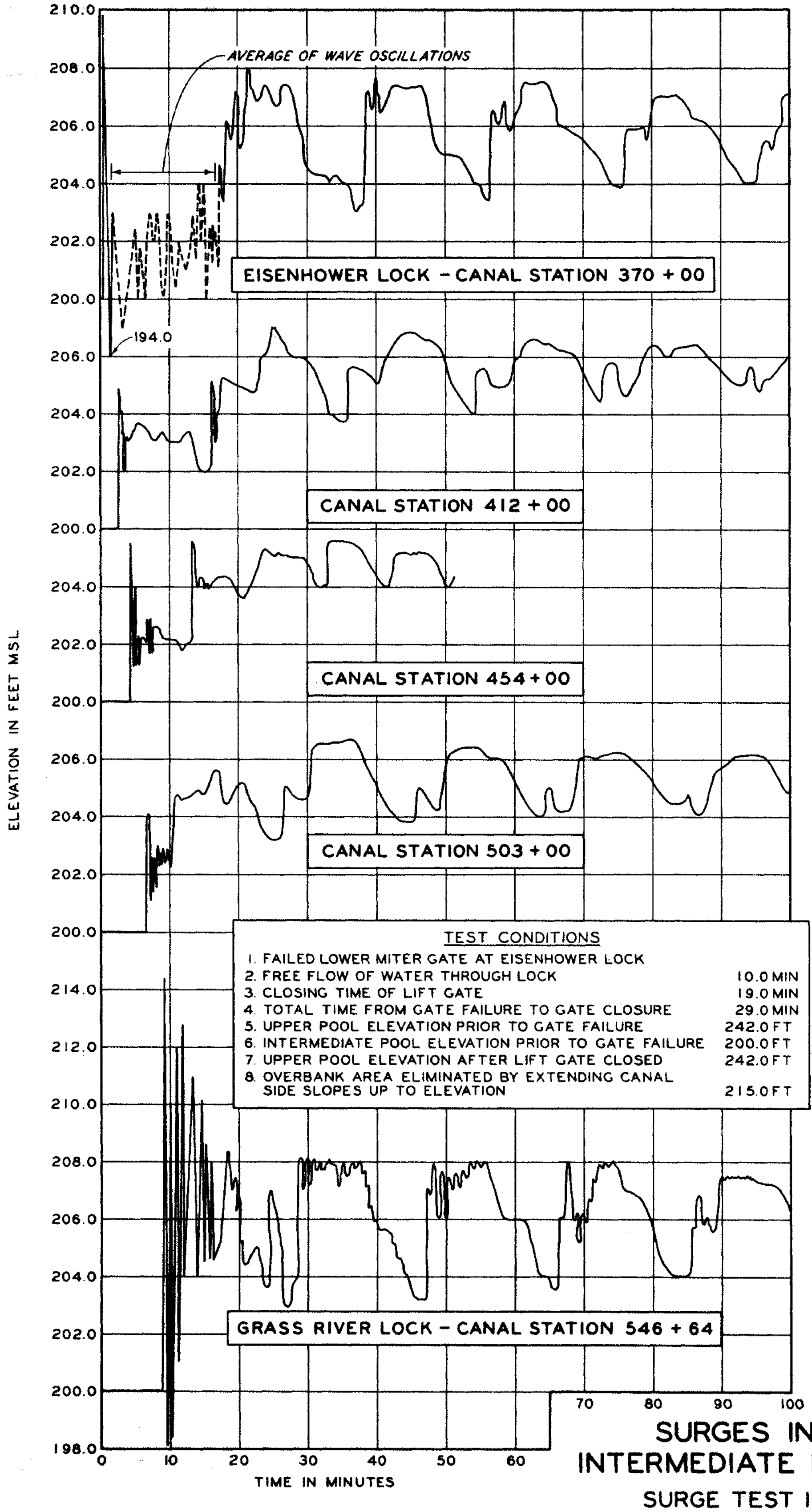
------ AVERAGE OF WAVE OSCILLATIONS
.... ABOVE TOP OF LOCK WALLS (ELEV 205.0)

TEST CONDITIONS

1. FREE FLOW OF WATER THROUGH LOCK
2. UPPER POOL ELEVATION PRIOR TO GATE FAILURE 242.0 FT
3. INTERMEDIATE POOL ELEVATION PRIOR TO GATE FAILURE 200.0 FT
4. UPPER POOL ELEVATION AFTER LIFT GATE CLOSED 242.0 FT

SURGES IN INTERMEDIATE POOL

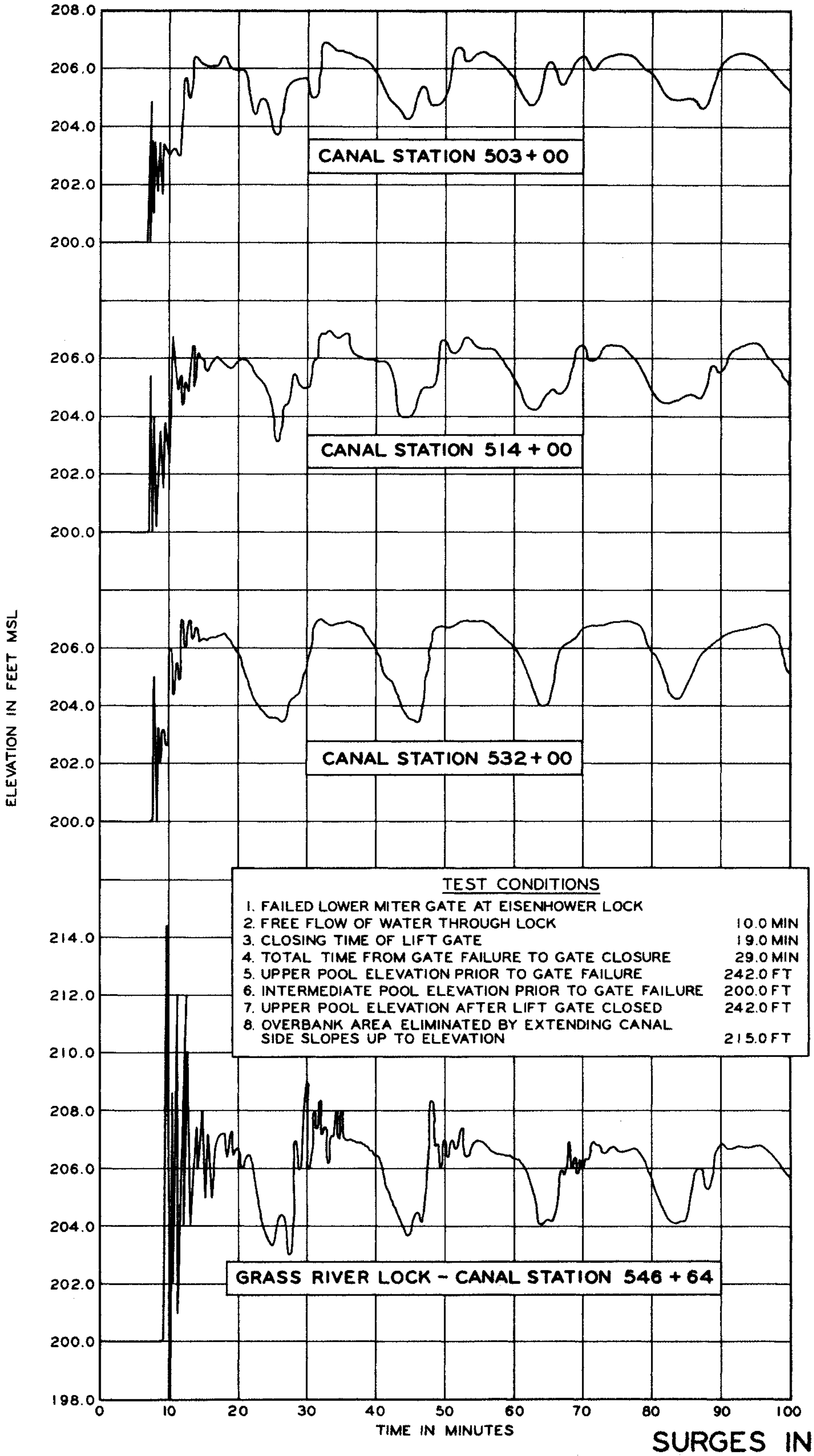
SURGE TESTS 6 AND 7



SURGES IN INTERMEDIATE POOL

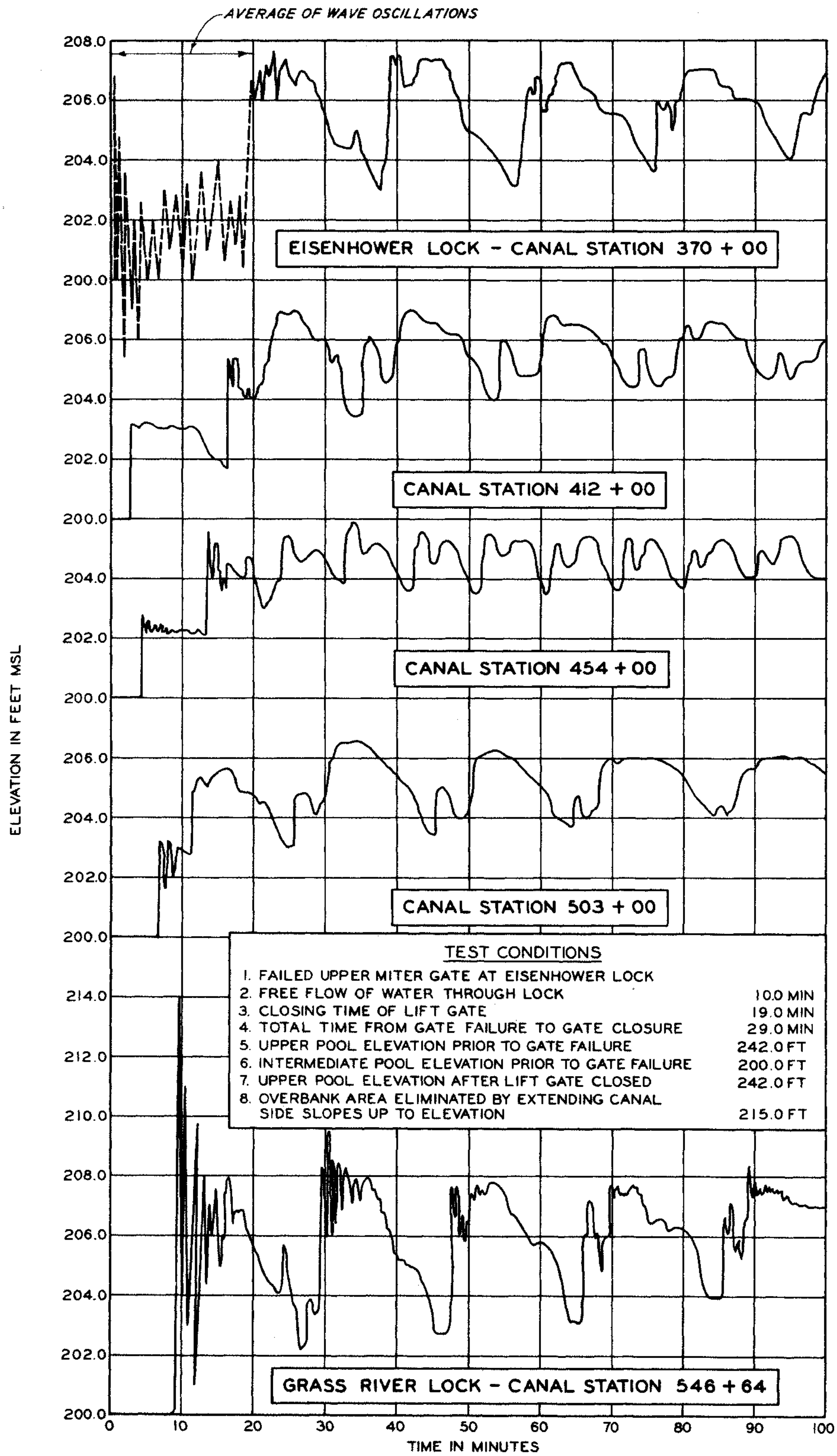
SURGE TEST 10

PLATE 8



SURGES IN INTERMEDIATE POOL

SURGE TEST 10 (RERUN)



SURGES IN INTERMEDIATE POOL

SURGE TEST 11